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(54) Method of converting polycrystalline semiconductor material into monocrystalline semiconductor material.

(57) In order to obtain recrystallization in polycrystalline or amorphous semiconductor material (4) by means of laser radiation (6) having a wavelength to which the material (4) is practically completely transparent at least at room temperature, the layer of semiconductor material (4) is accommodated in a multilayer structure (2). The multilayer structure (2) comprises, besides the semiconductor layer (4), a top layer (5) and a first insulating layer (3). The thicknesses of the layers (3, 4 and 5) can be so chosen that in the structure (2) a sufficient amount of radiation is absorbed to rapidly attain recrystallization without the subjacent substrate (10) being excessively heated.

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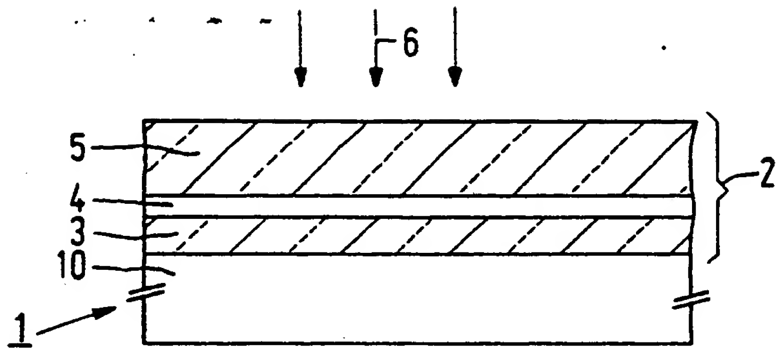

FIG.1

Method of converting polycrsytalline semiconductor material into monocrystalline semiconductor material.

The invention relates to a method of converting polycrystalline or amorphous semiconductor material into monocrystalline semiconductor material, in which on a substrate a layer structure comprising a layer of polycrystalline or amorphous semiconductor material between a first electrically insulating layer and a coating layer is irradiated by a radiation source which supplies practically monochromatic electromagnetic radiation, to which the polycrystalline or amorphous semiconductor material is practically completely transparent at least at room temperature, the energy being sufficient to heat the layer structure in such a manner that the polycrystalline or amorphous semiconductor material is converted at least locally into monocrystalline semiconductor material.

The invention further relates to a device provided with monocrystalline semiconductor material, which is applied by means of such a method.

Methods of this kind may be advantageously used, for example, in the manufacture of so-called three-dimensional integrated circuits, in which, after an insulating layer has been applied, which protects underlying circuits, such as memory matrices registers, multiplexers etc., from the influences of further operations, again monocrystalline regions have to be applied on this insulating layer for transistors or other circuit elements. Another field of use is, for example, the manufacture of monocrystalline semiconductor material on an insulating substrate on behalf of opto-electronic elements.

A method of the kind mentioned in the opening paragraph is known from Japanese Patent Application laid open to public inspection Kokai No. 57-124423. By means of the method described therein, a layer of polycrystalline silicon located between two SiO_2 layers is recrystallized by irradiating it by electromagnetic radiation originating from a CO_2 laser. The wavelength of this radiation is about 10 μm, to which the polycrystalline silicon is substantially completely transparent at room temperature so that substantially no energy is absorbed herein on behalf of recrystallization.

In general, a radiation source is therefore preferably chosen which has such a wavelength that the semiconductor material sbsorbs a largest possible amount of energy, as in the case of polycrystalline silicon for example an argon ion laser. On the other hand, the use of, for example, a CO_2 laser has, apart from the lower absorption in polycrystalline silicon, various advantages as compared with the argon ion laser. In the first place, the emission is more stable and hence the intensity of the emitted radiation is more constant. Besides, the power of a CO_2 laser is considerably higher than that of an argon ion laser, while the light output is higher. Moreover, the cost price is more favourable. In addition, due to the higher power, several beams can be produced simultaneously by a CO_2 laser, which is favourable for given applications.

The invention has for its object to provide a method, in which radiation is used, to which polycrystalline semiconductor material is practically completely transparent, and nevertheless a sufficient absorption occurs in the layer structure to rapidly heat the semiconductor material to temperatures at which a substantially complete absorption is obtained.

A method according to the invention is for this purpose characterized in that at least 4 % of the energy supplied by the radiation source to the layer structure is absorbed in the layer structure and at most 60 % thereof is supplied to the underlying substrate.

The invention is based on the recognition of the fact that this can be achieved by a suitable construction of the layer structure, especially by mutually adapting the thicknesses of the various layers in such a manner that the first electrically insulating layer and the coating layer are rapidly heated. As a result, the interposed semiconductor material is also heated comparatively rapidly to a temperature at which it behaves practically metallically and absorbs a larger part of the radiation. If desired, the whole may be heated more rapidly by heating, as the case may be temporarily, by means of a heating element.

A preferred embodiment of a method according to the invention is characterized in that the coating layer in the layer structure has a thickness of practically $\frac{m}{4}\lambda^{I}$ and the layer of polycrystalline semiconductor material and the electrically insulating layer have thicknesses of practically $\frac{n}{4}\lambda^{II}$ and $\frac{n'}{4}\lambda^{III}$, respectively, where m is even, n and n' are odd and λ^{I}, λ^{II} and λ^{III} are the wavelengths of the electro-agnetic radiation in the coating layer, the layer of polycrystalline semiconductor material and the first electrically insulating layer, respectively.

With such a layer structure, an absorption at room temperature of about 8% can be reached, while only 32 % of the radiation energy is supplied to the underlying substrate. In the structure as shown in Japanese Patent Application laid open to public inspection Kokai No. 57-124423, a thickness of the coating layer is not mentioned, it is true, but with usual thicknesses of this layer still more than

about 60 % of the electromagnetic energy is supplied to the underlying substrate, while with the relevant thickness of the coating layer the absorption in the layer structure is very low (about 1 %).

The invention will now be described more fully with reference to a few embodiments and the drawing, in which:

Fig. 1 shows a layer structure suitable for a method according to the invention, while

Fig. 2 illustrates diagrammatically the variation as a function of the thickness of the layer of polycrystalline semiconductor material of the absorption, the transmission and the reflection in such a layer of energy supplied by a monochromatic radiation source, and

Fig. 3 shows a multilayer structure suitable for use of a method according to the invention.

The figures are schematic and not drawn to scale. Corresponding elements are generally designated by the same reference numerals.

Fig. 1 shows a device 1 comprising on a substrate 10 a layer structure 2. The substrate 10 is, for example, a silicon body and may comprise, for example, finished semiconductor circuits. However, the substrate 10 may alternatively consist of electrically insulating material (glass or sapphire). The layer structure 2 in this embodiment comprises a first layer 3 of silicon dioxide having a thickness of about 1.25 µm, which corresponds to about $\frac{1}{2}\lambda^{III}$, where λ^{III} is the wavelength in silicon dioxide of the radiation emitted by a CO_2 laser (about 10.6 µm in vacuo), and a polycrystalline silicon layer 4 having a thickness of about 0.77 µm, which corresponds to about $\frac{1}{2}\lambda^{II}$, where λ^{II} is the wavelength in polycrystalline silicon of such a radiation. The layer structure further comprises a coating layer 5 of silicon dioxide having a thickness of about 2.5 µm corresponding to about $\frac{1}{2}\lambda^{I}$, where λ^{I} is again the wavelength in silicon dioxide of the radiation emitted by a CO_2 laser. If desired, thin layers (not shown) of, for example, silicon nitride may be situated between the various layers and these thin layers may act as diffusion inhibitors and ensure a better wetting or a satisfactory thermal and mechanical adaptation. The overall thickness of the double layer comprising an intermediate layer and the layers 5,4,3 is again about $\frac{1}{2}\lambda^{I}$, $\frac{1}{2}\lambda^{II}$ and $\frac{1}{2}\lambda^{III}$, respectively.

In certain applications, for example, in the manufacture of so-called three-dimensional IC's or layers of polycrystalline silicon applied to electrically insulating substrates, it is desirable to convert the layer 4 completely or in part into monocrystalline silicon in order that active elements, such as transistors or other circuit elements, can be formed therein.

In accordance with the invention, the layer structure 2 is irradiated for this purpose by monochromatic radiation 6 originating from a CO_2 laser. At room temperature, the layer 4 transmits such a radiation substantially completely, however, so that without special steps the desired heating to the melting point and the subsequent recrystallization to monocrystalline silicon require a considerable amount of energy and time. A large part of the non-absorbed energy may additionally penetrate into the substrate 10 and cause damage therein; thus, if circuits have already been formed, conductor tracks may melt entirely or in part due to the heating, while out-diffusion may occur in semiconductor zones due to the increased temperature.

The layer structure shown here absorbs in the first instance a sufficient amount of energy in the layers 3 and 5, however, to rapidly heat the polycrystalline silicon layer 4 to a temperature of practically 800°C. At this temperature (and higher temperatures) the silicon has a substantially metallic character for the relevant wavelength and substantially the whole amount of energy is absorbed in the layer 4. This rapid heating of the layer structure 2 is reached already with an absorption in the layer structure 2 from about 4 % of the energy of the radiation 6 (at room temperature). The process of heating can be accelerated by heating the device 1, if desired, beforehand by other means, for example by placing the whole on a substrate heater. The temperature in the substrate 10 must of course not increase to such an extent that the aforementioned damage occurs.

Although in the layer structure 2 of Fig. 1 thicknesses are chosen for the layers 3, 4 and 5 which are closely related to the wavelength used for the radiation used, a certain variation is possible around these thicknesses, whilst nevertheless the condition is satisfied that the absorption is sufficiently high (4 % or more) and nevertheless the transmission of the radiation 6 and hence the part of the energy reaching the substrate 10 remains at an acceptable level (< 60 %).

This is explained with reference to Fig.2, in which for the layer structure 2 the absorption (curve 7), the transmission (curve 8) and the reflection (curve 9) for the radiation 6 having a wavelength of 10.6 µm, respectively, are shown

with varying thickness of the intermediate layer 4, as obtained at room temperature. It appears from the Figur that the transmission is low (< 45 %) with a sufficiently high absorption (> 8 %) when the thickness of the polycrystalline silicon varies between $0.2\lambda^{II}$ and $0.3\lambda^{II}$.

In a similar manner, a certain spread in the thicknesses of the coating layer and the first electrically insulating layer proves to be possible around the values $\frac{1}{2}\lambda^{I}$ and $\frac{1}{4}\lambda^{III}$, respectively, whilst the absorption still amounts to at least 4 % with an admissible transmission (<60 %). It should be noted that between the polycrystalline silicon layer 4 and the SiO_2 layers 3,5 adapted thin layers - (about 10-20 nm) may be provided consisting, for example, of silicon nitride. These layers serve on the one hand to obtain a satisfactory adhesion between the layers and on the other hand to optimize the temperature profile in the layer structure or to neutralize mechanical stresses. Moreover, silicon nitride has a satisfactory etching selectivity and a chemically inert character.

In a more general sense, it has been found that the aforementioned condition (absorption > 4 % with a transmission < 60%) is satisfied when for the top layer a thickness of approximately $\frac{m}{4}\lambda^{I}$ is chosen, where m is an even number, and when for the intermediate layer and the first electrically insulating layer thicknesses of approximately $\frac{n}{4}\lambda^{II}$ and $\frac{n'}{4}\lambda^{III}$ are chosen, where n and n' are odd numbers.

Fig. 3 finally shows an extension of the multilayer structure 2 with a subjacent additional poly crystalline silicon layer 12, which is separated from a substrate 10 by an additional electrically insulating layer 11 of silicon oxide.

The polycrystalline layer 12 may be, for example, heavily doped and may form part of a wiring pattern connecting circuit elements formed in the substrate 10 to semiconductor elements to be provided in the monocrystalline silicon to be formed. It also-holds for this structure that with irradiation by electromagnetic radiation 6 originating from a CO_2 laser recrystallization of the layers 4 and 12 occurs with thicknesses of the layers 3,4,5, as indicated above. A further optimization is obtained by again choosing for the layers 11 and 12 thicknesses of approximately 1.25 μm and 0.77 μm, respectively.

In a more general sense, for the layers 11 and 12 thicknesses are chosen around values of $\frac{n''}{4}\lambda^{IV}$ and $\frac{n'''}{4}\lambda^{V}$, where n" and n"' are odd, while λ^{IV} and λ^{V} are the wavelengths of the electromagnetic radiation in the additional electrically insulating layer and the additional layer of polycrystalline semiconductor material, respectively.

Of course the invention is not limited to the embodiment described herein, but various modifications are possible for those skilled in the art without departing from the scope of the invention. For example, in the above embodiment, instead of a CO_2 laser, a CO laser or a neodymium-doped YAG laser may also be used. Furthermore, other semiconductor materials, such as, for example, a III-V material, such as GaAs, may be chosen for opto-electronic applications, or II-VI materials or a combination of GaAs and silicon may be chosen in one semiconductor device. If required, a different laser may be chosen having a wavelength at which the GaAs is practically completely transparent, such as a neodymium-doped YAG laser. Instead of silicon dioxide, silicon monoxide may also be used both in the intermediate layers and in the coating layer. Besides, amorphous silicon may be chosen for the layer 4.

Claims

1. A method of converting polycrystalline or amorphous semiconductor material into practically monocrystalline semiconductor material, in which on a substrate a layer structure comprising a layer of polycrystalline or amorphous semiconductor material between a first electrically insulating layer and a coating layer is irradiated by a radiation source supplying practically monochromatic electromagnetic radiation, to which the polycrystalline or amorphous semiconductor material is practically completely transparent at least at room temperature, the energy being sufficient to heat the layer structure in such a manner that the polycrystalline or amorphous semi-conductor material is converted at least locally into monocrystalline semiconductor material, characterized in that at least 4 % of the energy supplied by the radiation source to the layer structure is absorbed in the layer structure and at most 60 % thereof is supplied to the underlying substrate.

2. A method as claimed in Claim 1, characterized in that in the layer structure the coating layer has a thickness of practically $\frac{m}{4}\lambda^{I}$ and the layer of polycrystalline or amorphous semiconductor material and the electrically insulating layer have thicknesses of practically $\frac{n}{4}.\lambda^{II}$ and $\frac{n'}{4}.\lambda^{III}$, where m is even and n and n' are odd, while λ^{I}, λ^{II} and λ^{III} are the wavelengths of the electromagnetic radiation in the coating layer, the layer of polycrystalline or amorphous semiconductor material and the first electrically insulating layer, respectively.

3. A method as claimed in Claim 1 or 2, characterized in that the layer structure between the first electrically insulating layer and the substrate has at least a double layer comprising an additional electrically insulating layer and an additional layer of polycrystalline semiconductor material present thereon.

4. A method as claimed in Claim 3, characterized in that the additional insulating layer and the additional layer of polycrystalline semi-conductor material have thicknesses of practically .λ^{IV} and .λ^{V}, where n" and n"' are even and λ^{IV} and $\lambda^{V}$are the wavelengths of the electromagnetic radiation in the additional insulating layer and the additional layer of polycrystalline semiconductor material, respectively.

5. A method as claimed in any one of the preceding Claims, characterized in that the electro-magnetic radiation originates from a CO_2 laser or a CO laser or an Nd-YAG laser.

6. A method as claimed in any on of the preceding Claims, characterized in that the substrate is beforehand at an elevated temperature.

7. A method as claimed in any one of the preceding Claims, characterized in that the substrate comprises a semiconductor body, in which circuit elements are formed.

8. A method as claimed in any one of the preceding Claims, characterized in that to obtain a better mutual adaptation, the layer structure is provided with at least one intermediate layer between a polycrystalline semiconductor layer and one or more of the other layers.

9. A device provided with monocrystalline semiconductor material which is obtained by means of a method claimed in any one of Claims 1 to 8.

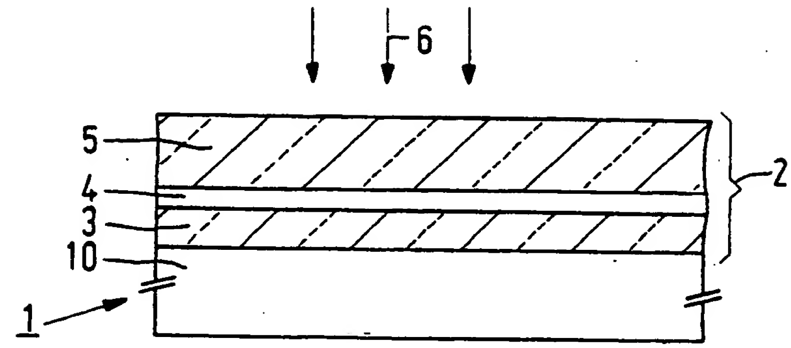

FIG.1

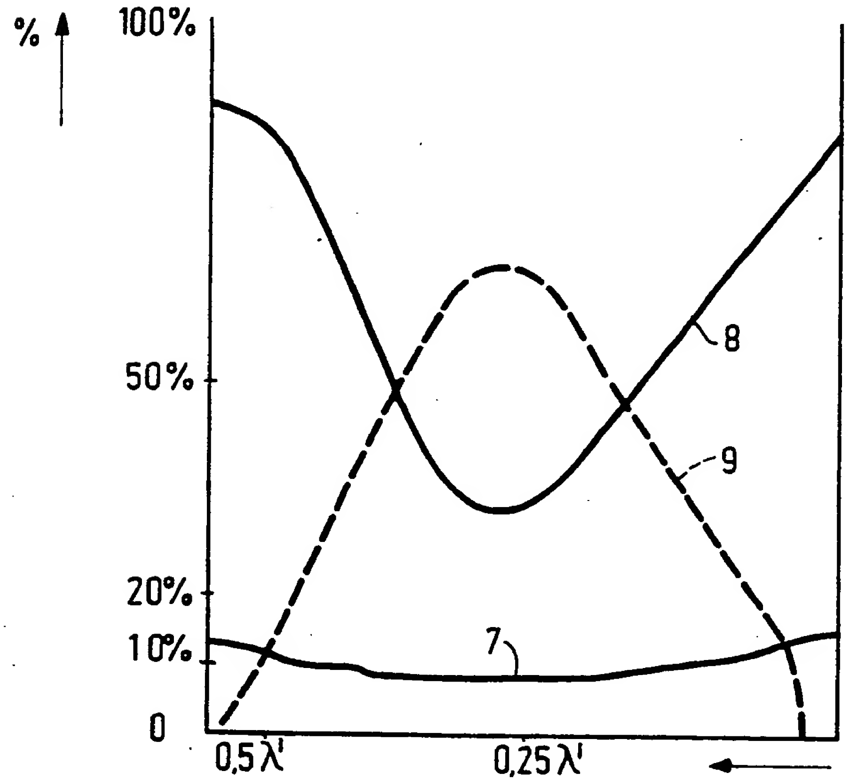

FIG.2

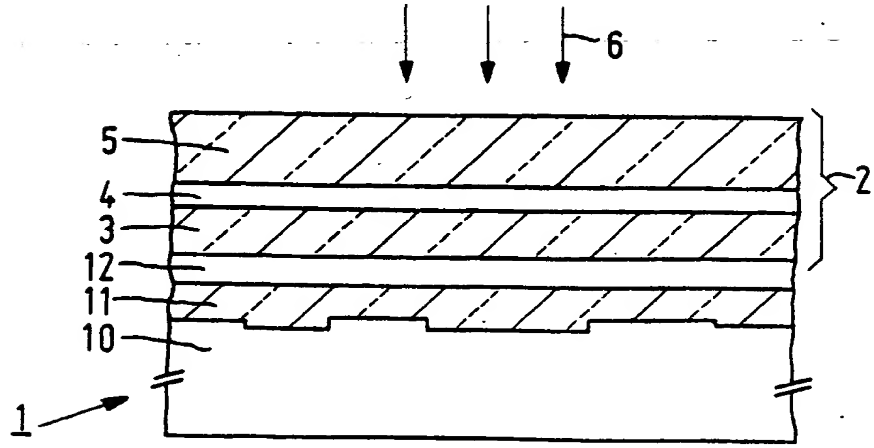

FIG.3

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EUROPEAN SEARCH REPORT

Application number

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X	EP-A-0 078 681 (XEROX CORP.) * Page 4, paragraph 6 - page 6, paragraph 2; page 7, paragraph 2; page 9, paragraph 3; claims 1,2,4,5,10; figure 5 * ---	1,5,8	H 01 L 21/268 H 01 L 21/20
A	EP-A-0 127 323 (FUJITSU LTD.) * Page 6, lines 17-34; claims 1-6; figures 2b,2c * ---	1,3,5, 7-9	
A	JAPANESE JOURNAL OF APPLIED PHYSICS, vol. 22, supplement 22-1, 1983, pages 205-208, Tokyo, JP; J.P. COLINGE et al.: "The use of selective annealing for growing very large grains in silicon on insulator films" * Figures 1-4 * ---	1,7	TECHNICAL FIELDS SEARCHED (Int. Cl.4)
A	IEEE ELECTRON DEVICE LETTERS, vol. EDL-3, no. 12, December 1982, pages 369-372, IEEE, New York, US; N.M. JOHNSON et al.: "Single-crystal silicon transistors in laser-crystallized thin films on bulk glass" * Page 369, column 2, paragraph 2 - page 370, column 1, paragraph 1 * --- -/-	1,5	H 01 L

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	27-06-1986	VANCRAEYNEST F.H.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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Application number

EP 86 20 0459

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
A	APPLIED PHYSICS LETTERS, vol. 45, no. 8, 15th October 1984, pages 854-856, American Institute of Physics, New York, US; K. EGAMI et al.: "Strong [100] texture formation of polycrystalline silicon films on amorphous insulator by laser recrystallization" * Figures 1,2; table I *		
A	GB-A-2 075 749 (FAIRCHILD CAMERA AND INSTRUMENT CORP.) * Page 1, line 38 - page 2, line 57; figures 1,6 *	1,6,7	
A	EP-A-0 109 499 (TEXAS INSTRUMENTS) * Page 5, line 1 - page 6, line 25; figures 1,2,4 *	1,6,7	TECHNICAL FIELDS SEARCHED (Int. Cl.4)
A	EP-A-0 028 934 (FUJITSU LTD.) * Figures 1-4 *	2,4	
A	IBM TECHNICAL DISCLOSURE BULLETIN, vol. 22, no. 12, May 1980, pages 5473-5474, New York, US; A.B. FOWLER et al.: "Selective laser annealing through quarter- and half-wave coatings" * Figures 1-3; page 5474, paragraphs 1-3 *	1,2,4	

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